Embrace Infant Care Unit
Final Report

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Stanford University
ME 113 – Mechanical Engineering Design
Professor Ken Waldron
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Abstract

Embrace Innovations' Infant Care Unit (ICU) is a product originally designed for use as a low-cost, electricity-free alternative to incubators in India. Instead of using electric heating, the ICU uses boiling water as its primary energy source. Through heat transfer, the heat from the water is used to heat a phase-changing material (PCM) with a melting point near human body temperature. Once heated into liquid form, the PCM can provide steady heat to an infant for an extended period of time as it cools down and re-freezes.

The ICU features three modules: the BabyBed, a comfortable cushion on which an infant rests; the SmartPak, a device that contains the PCM and stores energy for use; and the Heating Pouch, a container used to heat the SmartPak using boiling water. Standard use of the device involves pouring boiling water into the Heating Pouch to heat the SmartPak and placing the SmartPak and into the BabyBed once it has reached 37˚C. When heated properly, the ICU should be able to remain at 37˚C for approximately 8 hours.

The main goal of this project was twofold: to improve the temperature retention time to at least 6 hours and reduce the manufacturing cost of an ICU prototype by redesigning the SmartPak. The ICU design presented to us at the start of this project was a functional prototype designed by Embrace that was unable to maintain the required temperature for the time specified. After initial observations, we identified two main design issues causing excessive heat loss: a large thermal resistance due to the number of layers enclosing the materials within the SmartPak and a large amount of heat loss to the surrounding environment.

Given these areas of focus, we determined that the best way to accomplish these goals was to reduce internal thermal resistance in the SmartPak by reducing the total number of layers and reflect heat from the PCM away from the surrounding environment. After researching manufacturing methods and testing several prototypes, we developed a final design that features fewer layers in the SmartPak, reducing internal thermal resistance, and a reflective Mylar layer that acts as a thermal barrier reflects all heat to the baby. The final prototype partially satisfied both of the goals we had set out to accomplish: although it only extended temperature retention to 7 hours, the new design cost 7.5% less to produce. However, given that our proposed design features more thermally conductive materials not used in the final prototype, we believe that a prototype of our proposed design would be able to meet both of our project's goals.

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I. Introduction and Motivation

Introduction

Embrace Innovations started as a project at Stanford University in the course titled "Design for Extreme Affordability" with one idea in mind: to create an extremely affordable premature infant incubator for use in developing countries. Since then, Co-Founders Jane Chen and Rahul Panicker have developed a company dedicated to providing this low-cost product to families who otherwise would not be able to afford the care necessary to ensure that their children will live past the stage of infancy. Embrace Innovations is based in Bangalore, India and works to provide their care units to homes and hospitals alike *(Appendix A)*.

Motivation

The challenge that the company is currently facing is creating a product that is affordable at low volumes, easy to assemble, and aesthetically pleasing to their clients. Embrace is a relatively new company, which naturally does not have a large amount of current buyers due to its relatively recent launch. The need for a visually attractive product is also tied to this fact because visually attractive products are more easily marketed than products that are not.

Since the functionality of the incubator absolutely cannot be tampered with, the cost of the product is what becomes compromised to meet the needs of a new and developing company. The catch is that cost *reduction* is what is most important to the company! To help solve this problem, Embrace Innovations enlisted the help of the Stanford University Design Methods class, which will be referred to as ME 317 for the remainder of this paper.

The team of students selected from ME 317 were given the daunting task of reducing the cost of the Embrace Infant Care Unit without compromising the functionality of the incubator. After weeks of research and interviews, the team determined that the incubator's heat retention unit, otherwise known as the Smart Pak, is currently the most expensive part of the Infant Care Unit. Since redesigning the Smart Pak was a bit out of the scope of ME 317, they asked for a team from ME 113 to work on redesigning the Smart Pak to make it easy to assemble (after all, time is money) and more cost effective.

The remainder of this report will go into the details of the constraints of this project and how we, the ME 113 Embrace team, attacked the problem presented to us.

II. Functional Specifications

Objectives

When designing this project for the ME 113 Embrace team, the ME 317 team identified two possible projects :

1. Alternate PCM development and sourcing
2. **Development of PCM-water layer assembly (in the Smart Pak)**

We chose to look at the second project, development of PCM-water layer assembly, as it consisted a larger engineering scope with aspects of manufacturing, design, and thermal modeling.

The main objectives of this project as specified by Embrace were:

1. To reduce the number of parts in the SmartPak, making the product easier and faster to assemble and,
2. To redesign the Smart Pak to increase the product's the duration of warmth, while maintaining a temperature around 37°C

Currently, the product is advertised to maintain a temperature around 37°C for approximately 8 hours without needing to be reheated.

Requirements

In redesigning the prototype, we were given functional specifications by Embrace. We separated them into two categories, primary and secondary requirements as listed below:

Primary requirements

- Should be cheap
- Should preferably have lesser number of parts (lesser number of layers between the PCM and the baby results in longer duration of warmth to the baby, as the PCM has flat region around 37°C it takes about 40-60 mins for the temperature on the top of water layer to drop by 0.5°C)
- Components should be easier to handle and assemble
- The assembly should have a soft water layer on the top for the baby to comfortably rest on and to evenly distribute heat

- The PCM should be contained in a frame rigid enough to prevent liquid PCM from flowing and accumulating to one side
- Should be about the size of a baby (approximately 40cm X 24 cm)

Secondary requirements

- There shouldn't be any air gap between any of the layers for better thermal properties.
- Should contain about 500g of PCM
- Should be aesthetically good
- Should have thermistors on the top surface to monitor temperature
- For the assembly to heat properly , the thickness of the plastic sheet on the bottom side of the Smart Pak shouldn't be more than 0.6-0.7mm
- Top surface should be printable
- Should have thermistors on the top surface to monitor temperature (the assembly of thermistors should be such that it insulates thermistors, the mounting is reliable and doesn't look untidy)

III. Project Plan

Our ten week project plan consisted of four main parts: research, brainstorming, prototyping and testing. While we had originally planned for our approach to be linear from step to step, we found ourselves continuously iterating through each of them many times in non-consecutive orders as best suited our project needs. The task calendar that we have been keeping for this quarter is located in our appendix *(Appendix B)*.

Roughly speaking, much of the first two weeks of the quarter was spent on researching Embrace's current products. The next two weeks consisted of concept generation and the selection of three possible solutions to the problem we were given. The next two weeks consisted of rapid prototyping along with creating a thermal model to compare our ideas to the product given to us by Embrace. During weeks seven and eight, we went through a few iterations on what we decided would be our final design until we all had something that we agreed was presentation worthy. Weeks nine and ten have been solely dedicated to testing both the original product and our own along with writing this report and putting together our final presentation.

We found that setting weekly meeting times between ourselves and our project sponsor along with the ME 113 weekly coaching sessions was extremely helpful in terms of keeping us on track throughout the quarter. A typical week for us consisted of a presentation of our progress to Embrace on Monday, a group meeting on Tuesday, our coaching session on Thursday in the afternoon, and another group meeting Thursday nights. This set schedule allowed us to get work done, receive feedback from various resources, and then improve on our project in a continuous and repetitive fashion. Some of our group meetings included shopping trips while others had us seeking help from other professors on campus, but ultimately we were able to stick to our plan. This consistency not only allowed us to be productive, but also helped us to be efficient and execute each step of our creation process in a timely manner.

IV. Concept Generation and Selection

Embrace provided our team with a current version of the Embrace Care Unit, which we were allowed to take apart and dissect. To better understand the product, we will briefly introduce the various components of the Embrace Care Unit and explain how it is used.

Figure 1. Current Embrace Low-Cost Infant Warmer

The Embrace Care Unit, intended to provide warmth to clinically stable newborns, consists of 5 major components: the Embrace Heater, the Embrace Smart Pak, the Embrace Baby Bed, the Embrace Bed Sheet, and the Funnel (as shown in Figure 1).

Product Use

The Smart Pak is placed in the Heater, where it is placed beside the Heater's boiling water pouch. The boiling water is poured into the Heater's boiling water pouch through the use of a funnel. The thermal energy from the boiling water transfers to a Phase Change Material that is layered in the Smart Pak. The Phase Change Material (PCM) inside the Smart Pak then transfers heat to the Baby Bed for approximately 6-8 hours with the temperature maintained at 37°C. After about 45 minutes, LED lights and an alarm sound indicate that the Smart Pak is safe to put into the Baby Bed. After the Smart Pak is placed into the Baby Bed, the Embrace Bed Sheet is then wrapped around the infant. To reuse the system, the Smart Pak is removed from the Baby Bed and reheated with fresh boiling water in the Heater.

Dissection and Results

Embrace provided us with their current product, which we were allowed to take a part and dissect *(Appendix C).*

The current Embrace Care product consists of 9 layers (Figure 2) including the PCM and water layers, 7 layers not including the PCM and water layers. We found many of these layers to be redundant or in some cases counterproductive. For example, almost half of the Smart Pak's thermal resistance resided in the center PVC layer, according to our initial thermal model and calculations (*Appendix D).*

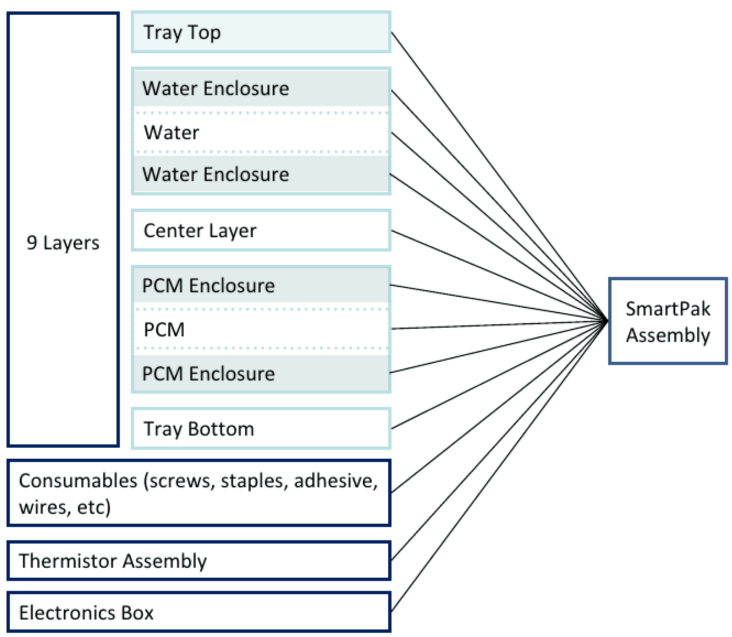


Figure 2. Smart Pak Assembly

The current product was held together by staples, which were a hassle to remove one by one. Due to the unaesthetic nature of the staples, a silicon covering was used to cover the staples. We found this assembly design to be extremely cumbersome and sought to eliminate these materials.

Lastly, after some calculations, we found that Embrace was overspending on production of the bottom PVC tray. We found that over 80% of the material was currently being wasted during vacuum forming *(Appendix E)*. After some research and consultation, we discovered that this waste was not due to the manufacturing process. Generally vacuum forming is extremely cheap in mass volume. The cost was unnecessarily being driven up by the manufacturer and is currently being investigated by Embrace.

Brainstorming

In brainstorming, we sought to come up with designs that incorporated the following ideas:

- No staples, no silicon tubing
- More heat sealing
- Combined water and PCM pouches to minimize layers
- Avoid surface heat sink
- Avoid plastic materials inside the Smart Pak

We also came up with selection factors to rank our concepts.

Selection Factors

- Engineering metrics
  - Thermal resistance of layers
  - Surface temperature
- Accessibility of materials
  - Sourced in India
  - Distance from Bangalore
- Ease of manufacturing and assembly
  - Time spent manufacturing and assembling product
- Cost of materials
  - Time spent acquiring materials
  - Monetary cost

In selecting a concept, we also had to keep in mind the accessibility of materials. Embrace is a small company based in Bangalore and requested to keep manufacturing within a certain radius from the company headquarters. Outsourcing materials and manufacturing out of the country would drive up traveling costs and most likely drive down product quality. Embrace's current sourcing map can be found in *Appendix M*.

While brainstorming and keeping the above selection factors in mind, we narrowed our ideas to three solid concepts. See *Appendix F.*

Proposed Concepts

Concept 1: Three layers, excluding PCM and water layer

This design focuses on reducing the assembly to the number of layers essential to holding the water and PCM in separate compartments. There are absolutely no excessive and unnecessary layers.

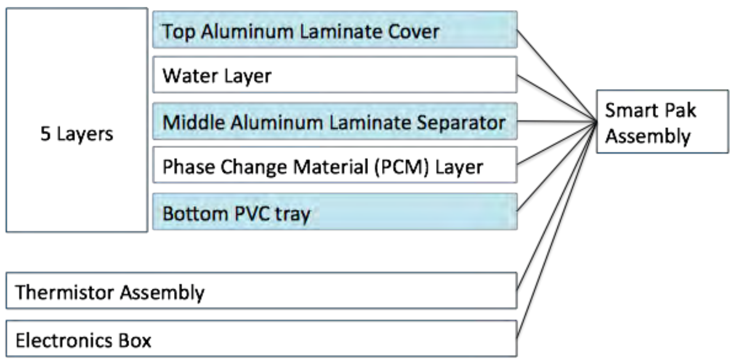


Figure 3. Concept 1 Smart Pak Assembly

The most important layers are kept: water for uniformity, PCM for heat retainment, bottom PVC tray for rigidity, and aluminate laminate layers for better heat transfer through the layers to the baby bed.

Concept 2: Two Pouch Module

This design focuses on decreasing assembly time and consists of one split module, an aluminum laminate packet split into two compartments: one for water and one for the PCM. To constrain the PCM's shape, we include a rigid bottom tray, which is attached to the aluminate packet through a snap ring. This avoids the use of staples and silicon lining, while maintaining the aesthetics of the product.

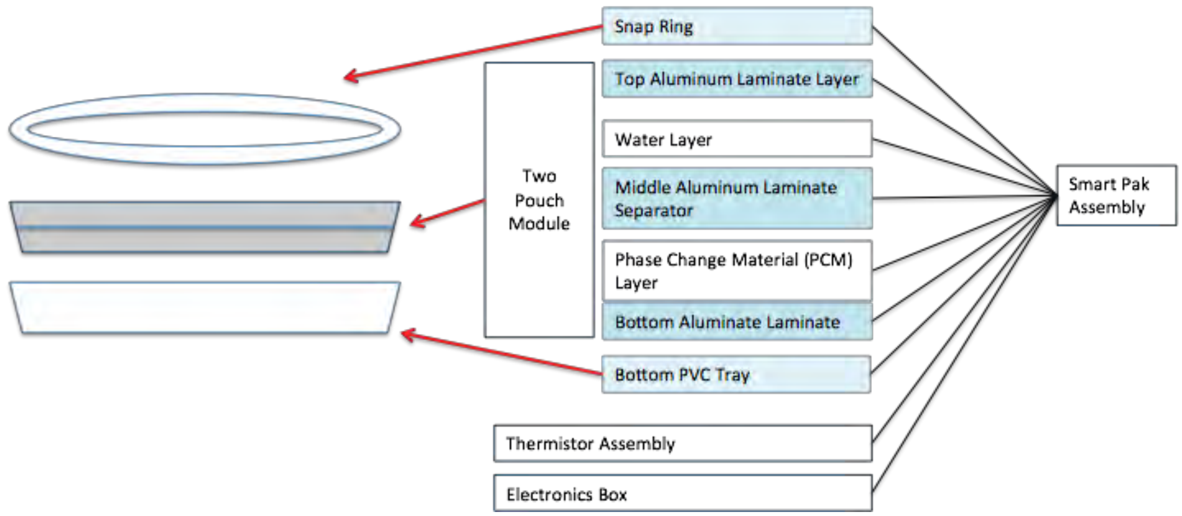


Figure 4. Concept 2 Smart Pak Assembly

In generating this concept, we explored various snap and press fits, which can be found in *Appendix G*. We settled on the geometry below based on the performance of the 3D-printed prototype.

Concept 3: Aluminum Middle Tray

Lastly, our third concept kept the current design, with changes only to the center PVC layer. As our thermal model suggests, the center PVC layer is the source of almost half of the Smart Pak's thermal resistance. Simply replacing the center PVC layer with a conductive material, such as aluminum would improve the thermal and heat storage properties of the entire Smart Pak.

Design Matrix

Key Criteria	**Current SmartPak**	**Concept 1: 3 layers**	**Concept 2: 2 pouch module**	**Concept 3: Aluminum middle layer**
Number of layers	2	**4**	3	2
Heat retention	1	**4**	3	2
Cost	2	**4**	3	1
Ease of assembly	2	1	**4**	1
Accessibility of materials	2	**4**	3	2
Baby Comfort	3	3	3	1
Meets primary specifications	**4**	1	**4**	**4**
TOTAL	16	21	**23**	13

Legend:
1st place = 4
2nd place = 3
3rd place = 2
4th place = 1

Our design matrix suggests that the two pouch module is the most feasible design, while meeting Embrace's functional specifications.

V. Design Methods Considerations and Justification of Materials

This section of our report will only consider the product we have recommended to Embrace Innovations because that is the only product that the ME 317 team has analyzed this quarter. The parts for this product are found in the appendix (*Appendix I*).

The ME 317 team had five main considerations for us throughout this quarter: manufacturing process, manufacturing costs, assembly process, assembly time and material costs. Our team was very intrigued by the materials originally chosen by Embrace Innovations for their Infant Care Unit due to their relatively high thermal resistances, but in the end we found that manufacturing and assembling an affordable, liquid-tight Smart Pak was much more difficult than we had anticipated.

The manufacturing processes and associated costs of each of our concepts drove our raw material selection decisions. Sheet metal, which rigid and thermally conductive, would have simply been too expensive to manufacture whereas plastic and film processes are relatively cheap. The assembly process and times drove our concept decision. We were very focused on a cheap product that worked extremely well on a thermal level, but had not considered how the product would actually come together physically. By forcing ourselves to think about assembling the product, we were able to narrow our concepts down to the product most producible. Finally, the material costs had to be considered because the main focus of ME 317 was to have a product that would reduce cost. Choosing expensive materials was simply not an option for us, which drove us to choose many materials that Embrace Innovations currently uses in more efficient ways.

The materials we chose were not only cheap, but also readily available in India. Our main goal has been to improve the thermal efficiency and manufacturability of the Smart pack while staying within Embrace's and ME 317's constraints. We have added more of the Phase Change Material (PCM) that keeps the baby warm because we found it necessary to maintain a higher temperature for a longer time than the current Infant Care Unit Does. We chose aluminum laminate as our main product material because metal is more thermally conductive than plastic, but harder and more expensive to create liquid-tight seals. The plastic film in aluminum laminate makes the material heat-sealable, which allows us to easily manufacture and assemble a liquid-tight module. A constraint we were given by Embrace Innovations was to include a layer of water at the top of the Smart Pak to evenly distribute the heat provided by the PCM to the baby and to create a more comfortable surface for the infant to lay on. We chose to use filtered water, as opposed to tap water, because filtered water is much more hygienic than the tap water available in

India. Thermistors are needed to measure the temperature of the Smart Pak to ensure that the baby is always receiving the right amount of heat and stickers are needed to keep the thermistors in place and hide the heat-seals and make the product more marketable. Our last recommendations for the product were to include insulation and mylar beneath the Smart Pak in order to direct as much heat as possible up towards the baby.

VI. Final Design and Manufacturing a Prototype

In realizing our two-pouch module concept, we explored many manufacturing methods, which are listed below.

Manufacturing Methods Explored

- Vacuum forming
- Injection Molding
- Heat Staking / plastic rivets
- Ultra-sonic welding
- 3D Printing
- Press and snap fits
- Heat sealing
- Baffling
- Metal stamping
- Adhesive bonding

We decided to stick with heat sealing to manufacture the pouches, as Embrace already had the equipment, and heat sealing is a fairly rapid process.

The PVC tray used in the current Embrace Smart Pak product is manufactured using vacuum forming. We considered vacuum forming as a manufacturing process for our prototype tray, but because we wanted the tray to be sealed using press fits with a mating top ring (thus eliminating the useof staples and silicone beading used in the Embrace Smart Pak), Professor David Beach of the Mechanical Engineering department of Stanford University advised us to look into another method of forming the tray. Vacuum forming a geometry so that it can be press or snap fitted into another geometry is a very tricky ordeal, since those types of fits require tolerances that are not within the range of vacuum forming tolerances.

Professor Beach recommended us to use a process that did make snap and press fits possible : injection molding. We played around with the thought of injection molding the tray. The benefits of forming the tray through injection molding include eliminating the cost of staples and silicone beading to seal the tray, since snap fits would be built into the tray and top mating ring design, and making the finish touches in product assembly a lot faster to complete. However, we were unsure if Embrace would have been willing to switch from one process (vacuum forming) to a new one (injection molding). After some discussion with Ratul, Shristi and the ME 317 team, we realized that switching to injection molding the tray would not be an extremely big deal, because injection molding is already being used in the the product manufacturing: the electronics box attached to the Smart Pak is injection molded! The fact that an injection molded tray that snap fits to a top, mating ring could improve the appearance of the Smart Pak and reduce assembly time was a huge driving reason behind our motivation to injection mold the tray and ring in our *proposed* prototype.

We wanted to prove that our proposed tray and ring design with snap fits could be injection molded and would be able to fit securely enough to hold together the layers of aluminum laminate (vinyl, in the case of ME 113 prototype), aluminum sheet, PCM and water. Although the Stanford Product Realization Lab does have an injection molder, it was not ready for student use this quarter. Luckily, Professor Beach informed us that a very widespread form of prototyping an injection molded part was to 3D print the part, and Stanford PRL did have a 3D ProJet Printer available for our use. We 3D printed different snap fits and press fits (see *Appendix G1*), and after testing the fits, we decided to use a simple, rectangular press fit that was able to keep the different layers pressed together between the bottom tray and sealing ring. We also chose this simpler press fit over the more complicated snap fits because we thought it was tightly sealed enough even without a snap geometry, and it had a simpler (and therefore, cheaper and more manufacturable) design (see *Appendix G2*).

A small scale model of the entire tray and ring, with the chosen snap fit design built into both parts, were 3D printed to demonstrate the capability of the snap fit. We unfortunately were unable to 3D print a full scale model, due to dimension limitations of the 3D ProJet Printer and the cost of printing such large pieces.

In prototyping, we were limited to the materials we could find in the prototyping room on campus, Room 36, or in stores nearby. One of our company liaisons visited the Bay area for a week and provided us PCM and water bags. However, we were not able to obtain aluminum laminate, a material used in the current product, so we substituted this material with vinyl, a material readily found in Room 36.

Note: Because we were constrained to using vinyl, we expect our prototype to perform not as well as if it were to be composed of aluminum laminate, which is the material recommended to Embrace in the final design.

See *Appendix H* for prototype assembly and process photos.

VII. Testing

Once our Smart Pak prototype was assembled, our next step was to test it's thermal capabilities and compare its performance to that of the Embrace product, as well as to determine whether or not design specifications were met.

In order to compare the performances of the Embrace product and our ME 113 prototype, both were heated and their temperatures were monitored over a period of time. Although we would have liked to test both products at the same time, this was not possible because our ME 113 prototype did not have a full-scale tray and ring assembled. A heat analysis of our prototype without the tray and ring would not have been an accurate portrayal of it's performance because the tray is an important thermal layer of the proposed Smart Pak design. Our solution to this problem was to use the same PVC tray from the Embrace Prototype to act as the bottom tray. We believe that the PVC tray was an adequate substitute because the bottom tray in our proposed prototype was modeled after it's exact dimensions and thickness.

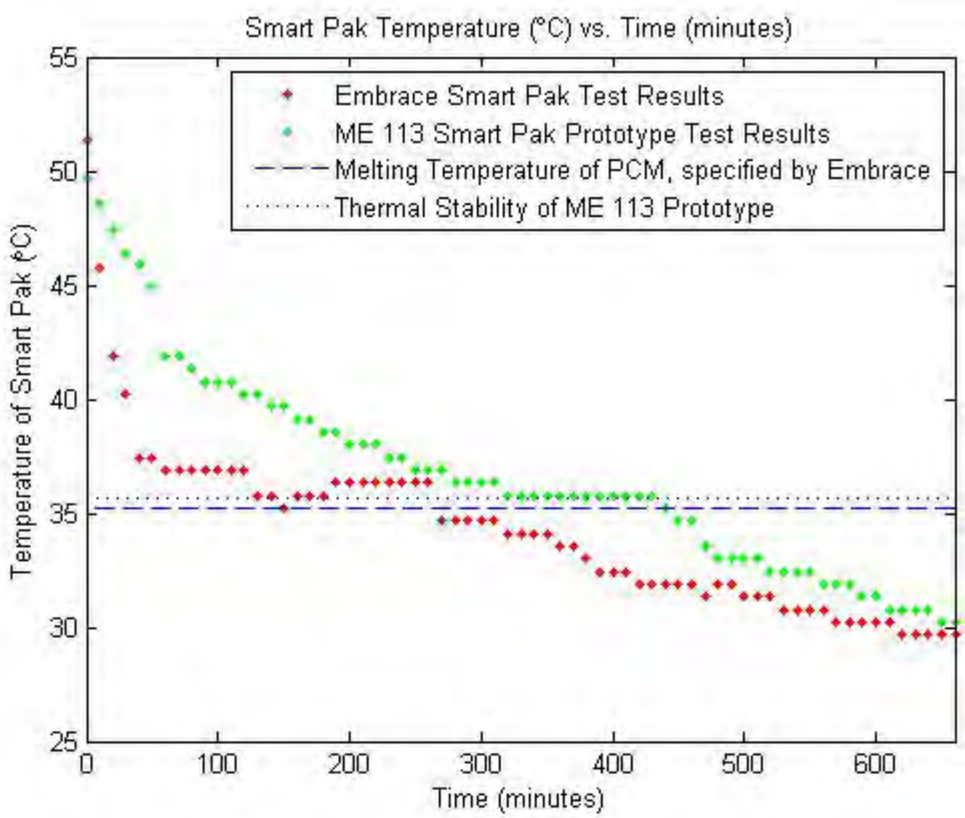
Since we had only PVC tray, testings of each product had to be conducted separately. We made sure that both tests were conducted in the same manner and around the same time of day, and that the ambient temperatures during each test were close enough so that any differences would be negligible.

The Embrace Smart Pak was tested first. It was heated from boiling water through the Embrace Heater, and was then taken out of the heater when it reached a temperature higher than 100 degrees Fahrenheit and also when all of the PCM had liquified. The Smart Pak was then placed inside the Embrace Baby Bed, and both were set down on a flat wooden table. The ambient temperature of the room at the beginning of the test was measured and recorded to be 86 degrees Fahrenheit. The temperature at the top of the Baby Bed was recorded after ensuring that the value was consistent throughout the entire top layer, and the temperatures were measured at ten minute intervals until the Smart Pak eventually reached the ambient temperature of the room. A table of our collected data can be found in *Appendix M.*

Before we could test our ME 113 prototype, we had to make sure that the ambient temperature of the room was close enough to the ambient temperature at the beginning of the Embrace Smart Pak testing so that any differences wouldn't result in large inaccuracies of their thermal performances. Two days, after the first testing, at around the same time of the day that the Embrace prototype was tested, we measured an ambient room temperature of 85 degrees Fahrenheit. Because this was the closest we had gotten to the ambient temperature of the first testing, we decided to test our prototype then. The same processes were conducted: the Smart Pak was heated through the heater (the ME 113 prototype had to use the PVC tray from the Embrace Smart Pak) and then placed inside the Embrace Baby Bed, and was set down on the same flat, wooden table to be monitored at ten minute intervals until the temperature at the surface of the baby bed reached the ambient temperature. The PVC tray from the Embrace prototype was used to model our proposed tray design, so it was placed in the heater with our prototype and was used during temperature monitoring. A collection of thermal data from our ME 113 prototyping can also be found in the appendix (*Appendix D*).

VIII. Results and Conclusion

To better compare the performances of the ME 113 prototype and the Embrace prototype, we plotted the temperature and time data from each test on the same plot:



*MATLAB code for this plot can be found in the Appendix

The melting temperature of the PCM, indicated by Embrace to be 35.2 degrees Celsius, is marked on the graph, as well as the temperature at which the ME 113 prototype stabilizes at, which is around 35.7 degrees Celsius. The plot lines clearly indicate that the ME 113 prototype sustains heat much longer than the current Embrace product. While the Embrace Smart Pak does maintain temperatures above and around the 35-39 degree Celsius temperature range desired by Embrace, it only stays above 35 degrees right under 300 minutes (5 hours).

Based on our testing of the ME 113 prototype, we can see that it manages to stay within and above the 35-39 temperature range up to 440 minutes, which is equivalent to 7 hours and 20 minutes. This is a **46.7%** percent increase in the time the Embrace Smart Pak stays heated inside the Baby Bed within the desired temperature range.

Embrace wanted our 113 team to create a prototype that could hold a temperature of 37 degrees Celsius (with a positive and negative tolerance of 2 degrees) up to **8 hour**s. Although our prototype fell 9.3% below the maximum heating period, there is still a significant amount of improvement in temperature range and heat sustainment. Both of these trends are visibly seen on the plot above.

Considering that the ME 113 prototype used in the testing does not have the same material in our *proposed* prototype , we are very satisfied with the information collected from our comparison trials. We are assuming that the aluminate laminate layers in our proposed prototype are slightly more thermally conductive than the vinyl layers used in our manufacture modeling/testing prototype. Therefore it is extremely likely that we would have reported better results had we used the same materials used in our proposed prototype.

In conclusion, we are very proud to show that our ME 113 Smart Pak prototype met most of the design requirements specified by Embrace at the beginning of the quarter: It was able to sustain a temperature between 33-37 degrees Celsius for about 7 hours, which is within the required temperature range. Our product would also reduce the cost of materials by 7.5 % , and would reduce the manufacturing and assembly time by 10-25 %, depending on the experience of the manufacturers (credit goes to the ME 317 team for calculating these percentages).

This project was a great learning experience for us, both as a team and as individual engineers. We were given the opportunity and practice to interact with a customer that had a real-world problem, and we were very fortunate to be a part of the Embrace team, as this product provides an amazing solution to a serious, and widespread problem. Our weekly meetings with the Embrace and ME 317 team, as well as our coaching team, gave us a look into how engineering teams in the work field communicate and work together to complete a project.

We have learned about many different and interesting manufacturing processes, such as ultrasonic welding, 3D printing, injection molding, heat staking, and baffling, just to name a few. Through group brainstorming sessions, design consultation meetings, and rapid prototyping, we each developed and gained more experience as engineers.

Overall, we are very satisfied with the results of our final prototype and the recommendations we have come up with for Embrace Innovations. This class has been an amazing experience for us and we are very thankful for the opportunity we have been given this quarter to grow as students and engineers.

Acknowledgements

Our team would like to thank our coaches, Edith Wilson and Ankur Shah, and the ME 317 Embrace team for being incredibly encouraging advisors and partners throughout the entire quarter. We would also like to thank Professor David Beach and Marlo Kohn for their manufacturing advice not only for our prototypes, but also for mass production possibilities for Embrace Innovations.

To Professor Ken Waldron, thank you very much for teaching ME 113. We have all learned so much throughout this course and are very grateful for the opportunity to have worked with Embrace Innovations.

Last, but most certainly not least, we would like to thank our project managers, Srishti Sundram and Ratul Narain, without whom this experience would not have been possible. Our knowledge of the pros and cons of materials and processes has grown exponentially throughout these last 10 weeks. While the step from theory and modeling to actually developing a product was a slight challenge for us, it helped us to grow as engineers. We are extremely grateful that we were able to work with such an amazing company and for the support we received along the

Appendix

APPENDIX A: Embrace Innovations

http://www.embraceinnovations.com/

APPENDIX B: Task Calendar

April

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
7	8	9 2-4pm: Old Union 121 Task Mapping 6-7pm: Old Union 121 Kickoff Meeting with Embrace	10	11 1-3:30pm: Old Union 122 Deconstruction of Prototype; Concept Generation 3:30-4pm: Thornton 208 Coaching 8pm-?: Treehouse Brainstorm!	12	13 1-3:30pm: Old Union Concept Generation with ME 317 Team
14	15 9-11pm: Old Union 113 Embrace Conference	16 2-4pm: Old Union 113 Read BOM, Read Embrace Requirements, Brainstorm Layer Concepts	17	18 3:30-4pm: Thornton 208 Coaching 7-9pm: Old Union 121 Manufacturing Research	19	20
21	22 9-11pm: Old Union 218 Embrace Conference	23 2-4pm: Old Union 122 Concept Generation	24	25 3:30-4pm: Thornton 208 Coaching 7-9pm: Old Union 121 Concept Generation	26	27 1:30-?pm: Treehouse Set up 113 account; 3 solid concepts; Pugh matrix; BOM
28	29 9-11pm: Old Union 218 Embrace Conference	30 2-4pm: Old Union 122 Prepare Mid-quarter presentation; Concept Selection Matrix				

May

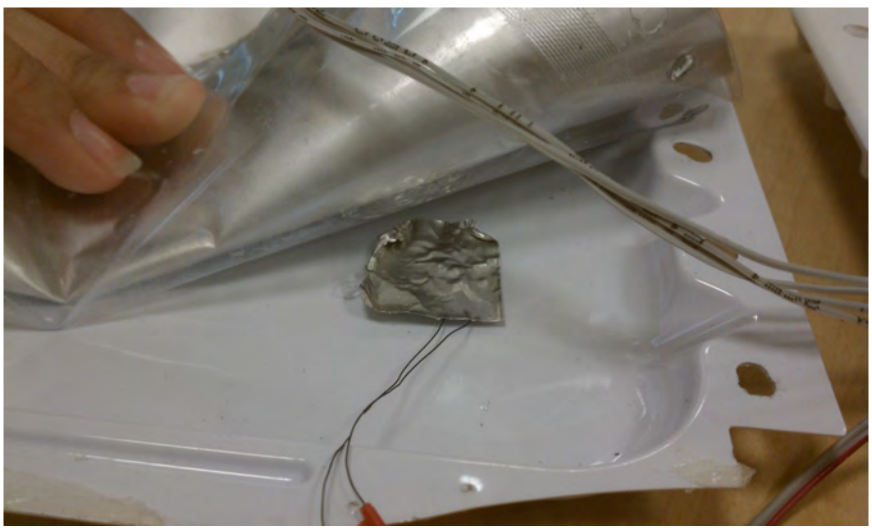
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 2-3pm: D.School Run presentation with Edith and Ankur	2 3:55-4:10pm: Classroom Mid-quarter Presentation 7-9pm: Old Union 121 Concept Selection	3	4
5	6 9-11pm: Old Union 218 Embrace Conference	7 2-4pm: Old Union 122 Meet w/ Prof Beach; Rapid Prototyping; Thermal Model	8	9 3:30-4pm: Thornton 208 Coaching 7-9pm: Old Union 121 Rapid Prototyping; Thermal Model	10	11
12	13 9-11pm: Old Union 218 **Embrace Conference** - Thermo Model - Mylar sewn	14 11-12pm: Ace - Rubber shoes shopping 1-2pm: Old Union Meet w/ Prof. Beach 2-4pm: Old Union 122 - PVC tray design - Rubber shoes design	15 2-3pm: Old Union Meet with Ratul	16 2:30-3pm: Old Union Coaching Prep 3:30-4pm: Thornton 208 Coaching 7-9pm: Old Union 121 Manufacturing and assembly process for 2 pouch module	17	18

19	20 <u>9-11pm: Old Union 218</u> **Embrace Conference** - Informational Documents	21 <u>2-4pm: Old Union 122</u> Manufacture Prototype	22	23 <u>2-3pm: Old Union</u> - Coaching Prep <u>3:30-4pm: Thornton 208</u> Coaching <u>7-9pm: Old Union 121</u> Discuss final costs with ME 317	24	25
26	27 <u>9-11pm: Old Union 218</u> **Embrace Conference** - Testing Results	28 <u>2-4pm: Old Union 122</u> - Troubleshooting - Prepare final presentation and report	29	30 <u>2:30-3pm: Old Union</u> Coaching Prep <u>3:30-4pm: Thornton 208</u> Coaching <u>7-9pm: Old Union 121</u> - Troubleshooting - Prep final presentation & report	31	

June

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1 <u>7pm: Mirrelees</u> Final Report
2	3 <u>9-11pm: Old Union 218</u> **Embrace Conference** - Run through final presentation	4 <u>2-4pm: Old Union 122</u> - Make final presentation poster - Finish log books	5 <u>7pm: Mirrelees</u> Final Report	6 <u>6pm: MERL</u> Final Presentation Final Report Due Logbooks Due	7	8

APPENDIX C: Dissection Pictures



APPENDIX D: Thermal Calculations

Matlab code

```
%% SmartPak thermal calculations (updated)
% Assumptions:
%   1-D steady heat transfer
%   PCM is at 37 degrees C
%   Free convection
%   No contact resistance between layers
%   Top surface of Smart Pack is open to air (not in baby bed)
%   Heat transfer due to decal/top sticker is negligible

clc; clear all; close all;

%% Material thermodynamic properties
kAl = 205;          % W/m/K
kVinyl = .25;       % W/m/K
kWater = 0.58;      % W/m/k

hAir = 2;           % W/m^2/K
hRadAir = 5.9;      % W/m^2/K
hWater = 60;        % W/m^2/K value is suspect (ranges from 20-100)

tAl = 0.11;         % mm
tAlNew = 3;         % mm
tVinyl = .03;       % mm
tWater = 7.4;       % mm

AreaAl = 69920/(1000^2);            % m^2
AreaVinyl = 75000/(1000^2);         % m^2
AreaAlNew = AreaVinyl;              % m^2
AreaWater = 60000/(1000^2);         % m^2
AreaTopSurface = 60000/(1000^2);    % m^2

%% PCM properties
deltaHf = 166.3e3;              % J/kg

specificHeatSolid = 1.77;       % J/g/C
specificHeatLiquid = 2.41;      % J/g/C

%% Thermal resistance calculation
RAl = (tAl/1000)/(AreaAl*kAl);                  % K/W
RAlNew = (tAlNew/1000)/(AreaAlNew*kAl);         % K/W
RVinyl = (tVinyl/1000)/(AreaVinyl*kVinyl);      % K/W
RWater = 1/(AreaWater*hWater);                  % K/W
```

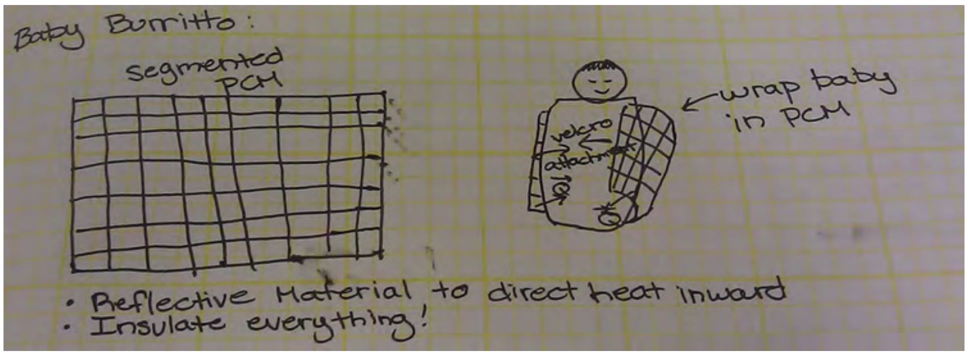
```
RAir = 1/(AreaTopSurface*(hAir + hRadAir));  % K/W

RTot = RAl + RWater + RVinyl + RAir         % Total thermal resistance [K/W]

TFusionPcm = 37;                        % PCM melting temperature [degrees C]
Tambient = 25;                          % Ambient temperature [degrees C]

%% required PCM mass calculation

q = (TFusionPcm - Tambient)/RTot;               % Total heat rate [W]

TSurface = TFusionPcm - q*(RAl + RWater + RVinyl)   % Surface temperature [degrees C]

timeNeededMax = 8*3600;                        % Minimum specified time [sec]
timeNeededMin = 6*3600;                        % Maximum specified time [sec]

heatNeededMax = timeNeededMax*q;                  % Required heat stored for maximum specified time [J]
heatNeededMin = timeNeededMin*q;                  % Required heat stored for minimum specified time [J]

massPcmNeededMax = heatNeededMax/(deltaHf + 1000*specificHeatSolid*(37-35))     % Mass of PCM needed for 8 hours [kg]
massPcmNeededMin = heatNeededMin/(deltaHf + 1000*specificHeatSolid*(37-35))     % Mass of PCM needed for 6 hours [kg]
```

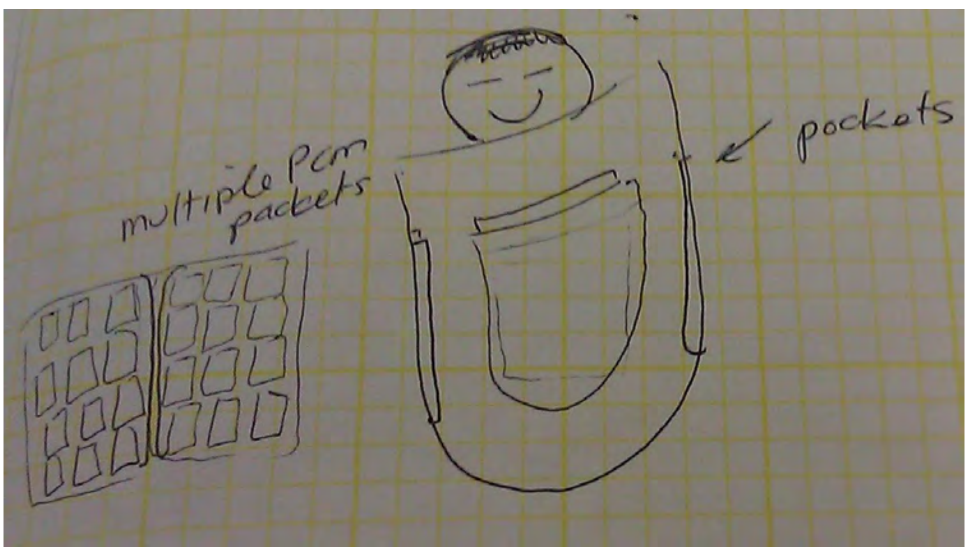
- 0.4127 K/W total thermal resistance
    - Water is 0.27786 K/W
    - Vinyl is 0.0016 K/W
    - Aluminum is insignificant (on the order of 10^-6 K/W)
- Water is the most thermally resistive material (11.63% of total resistance)
- Vinyl is .67% of total thermal resistance
- 0.6388 kg of PCM is required to maintain temperature for 6 hours

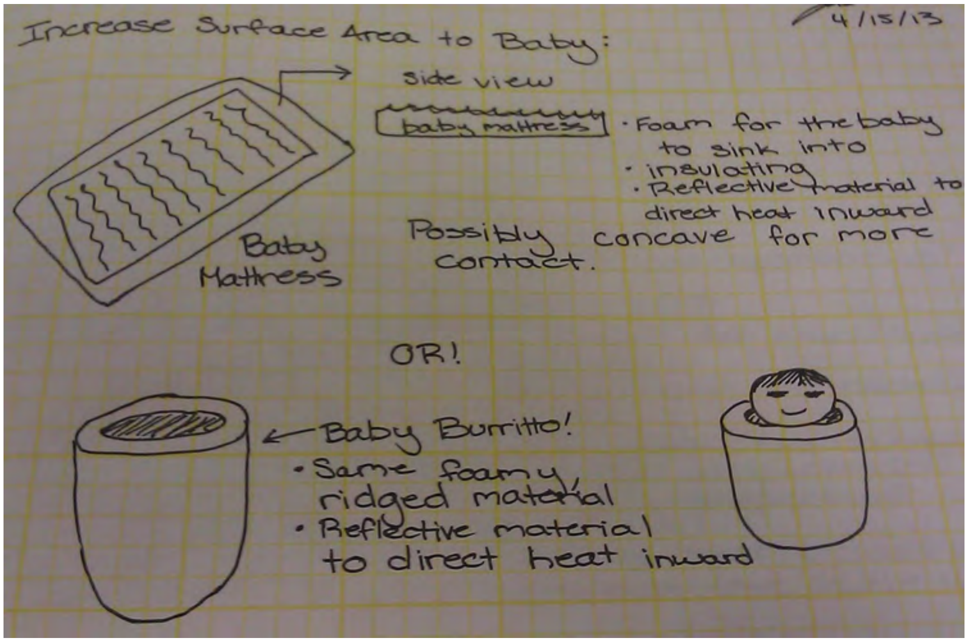
APPENDIX E: PVC Calculations

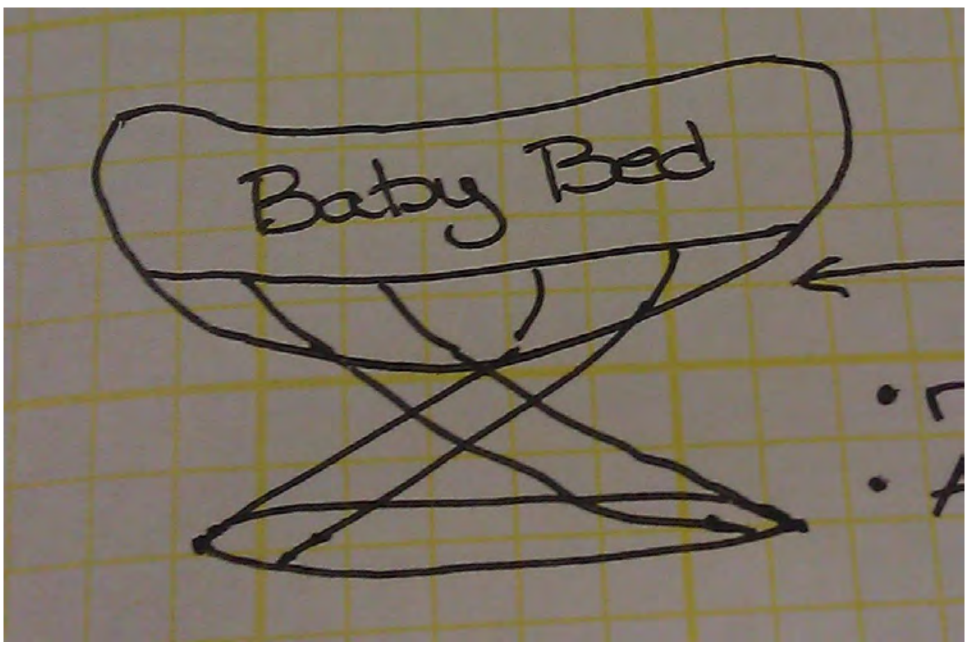
- 4 parts per 6’x3’ PVC sheet ≈ \$2.50 per part *not including vacuum forming*
- PVC tray is approximately 0.08 m^2 ≈ 0.8454 ft^2
- 18 ft^2 - (4 x 0.8454 ft^2) = 14.61825 ft^2
- **Based on our calculations, 81.2% of purchased PVC is wasted**

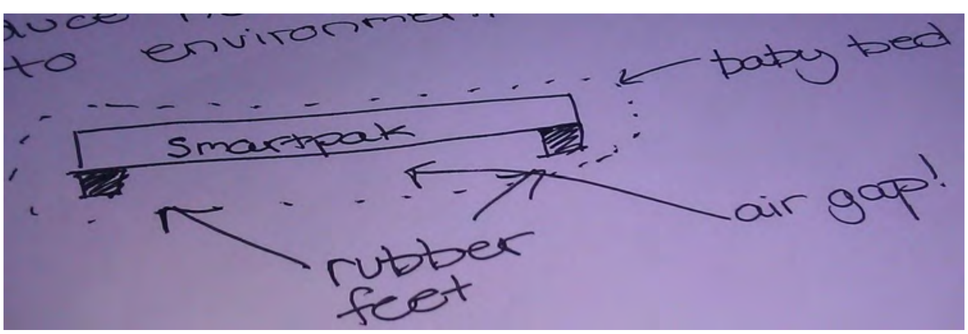
APPENDIX F: Brainstorming and Initial Concept Design Sketches



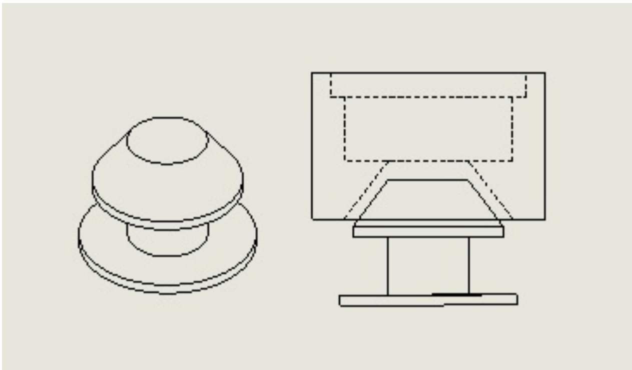


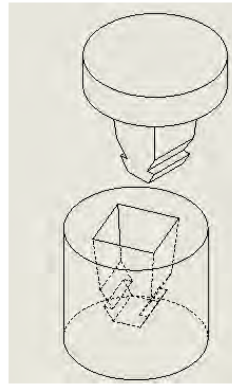

Increase Surface Area to Baby:
4/15/13
Side view
baby mattress
Baby Mattress
• Foam for the baby to sink into
• insulating
• Reflective material to direct heat inward
Possibly concave for more contact.
OR!
Baby Burritto!
• Same foamy, ridged material
• Reflective material to direct heat inward


Baby Bed

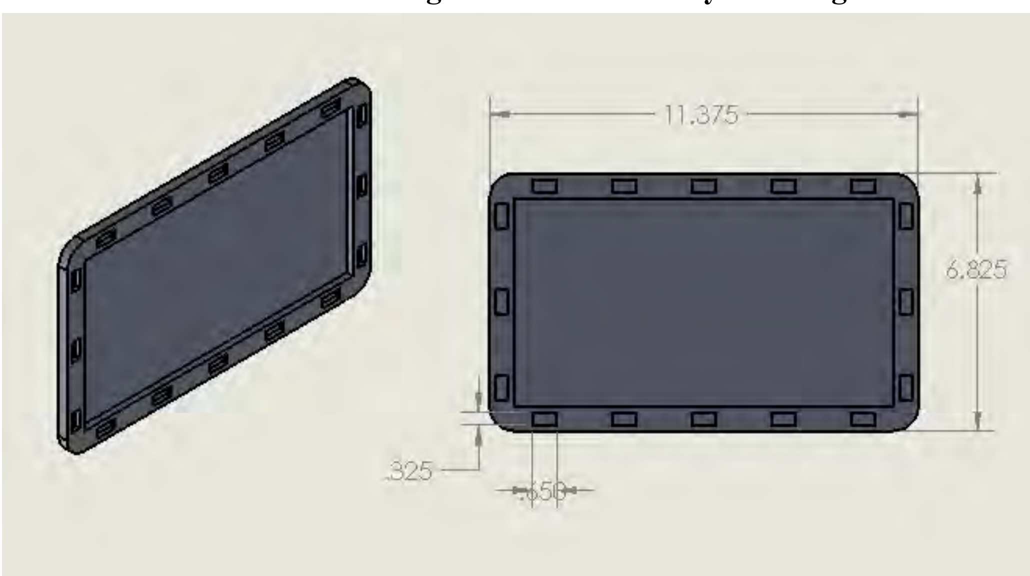

baby bed
Smartpak
air gap!
rubber feet

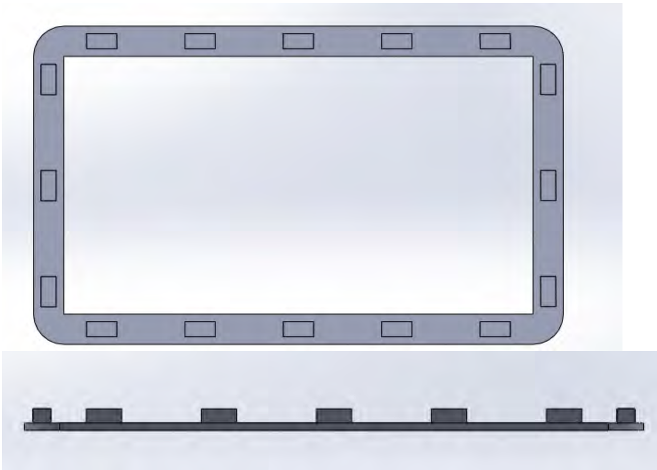
APPENDIX G1: Snap Fit Designs





APPENDIX G1: Press Fit Design Used in FInal Tray and Ring Parts





APPENDIX H: ME 113 Prototype Assembly and Process Photos




APPENDIX I: Parts Lists

ME 113 Final Prototype

Component Description	Qty	Unit	Process details	Notes
PCM	700	g		We added 200g of PCM to retain the necessary heat
Vinyl film pouches	2	Ea	17.5x10.5 inch pouches; heat sealed into the geometry given to us by Embrace Innovations	Outer Layers
Tap Water	~1.5	pints		
Aluminum Separator	1	Ea	15x9 inch sheets of aluminum; cut from disposable baking pans to the right geometry; 3 pans used in total; sheets were adhered	Aluminum Module Separator; aluminum is more conductive than plastic; thicker aluminum made for a sturdier divider
Duct Tape	56	inches	Edges of the aluminum separator were covered with duct tape	The edges of the cut aluminum were too sharp and kept poking holes into the vinyl pouches
Smart Pak tray bottom	1	Ea	3D printed with permanent press fits	Smart Pak Bottom Tray
Smart Pak tray top ring	1	Ea	3D printed with permanent press fits	Ring to hold dual compartment module and bottom tray together
Mylar	1	Ea	Sewed into the baby bed; 2 x 1 ft sheet	Reflects heat up towards the baby

Product Recommended to Embrace Innovations

Component Description	Qty	Unit	Process details	Notes
PCM	700	g		We added 200g of PCM to retain the necessary heat
Aluminum laminate film	2	Ea	42 x 24 x 0.0007 cm sheet of aluminum laminate; stamped	Outer Layers
Water, filtered, drinking water	750	ml		Filtered water is much more hygienic than tap water in India
THERMISTORS, NTC, R25=83K +/-3%, , R37=51.001-51.500K, (Grade E), B30/45=3953K+/-1%	2	Ea		Thermistor assembly (water layer)
425 aluminum tape	25x25	mm		Thermally conductive tape to hold thermistors in place
Insulation, 4 oz (polyfill), 100%	25x25	mm		Insulation at the bottom of the

Polyesteer, 120 Gsm Refer to Note -01 below				baby bed beneath the Smart Pak. Not included in the product we received for testing
Sticker - Water layer	1	Ea		Also holds thermistors in place. Makes the product more aesthetically pleasing and therefore more marketable
Sticker to cover heat sealing marks	1	Ea		Makes the product more aesthetically pleasing and therefore more marketable
Aluminum Laminate Separator	1	Ea	39 x 20 x 0.2 cm sheet of aluminum laminate; stamped	Aluminum Laminate Module Separator
Smart Pak tray bottom	1	Ea	Injection molded; 42 x 24 x 0.4 cm; permanent snap fits	Smart Pak Bottom Tray
Smart Pak tray top ring	1	Ea	Injection molded; 42 x 24 x 0.4 cm; 39 x 20 cm inner gap; permanent snap fits	Ring to hold dual compartment module and bottom tray together
Mylar	1	Ea	Sewn into the baby bed; 2 x 1 ft sheet	Reflects heat up towards the baby

APPENDIX J: Bill of Materials

Exchange Rate: 1 INR = 0.02 USD

Weights:

SubAssembly	Embrace P/N	Description	Manufacturer	Manufacturer P/N	Qty	Unit	Unit Cost (INR)	Total Cost (INR)	Unit Cost (USD)	Total Cost (USD)	Volume Pricing (INR) SmartPak Units/Mo		
											100	500	1000
2-pin connector	0027-00005-000	Crimp Terminal	Molex	8701039	2	EA	2	4	0.04	0.08	2	1.88	1.75
2-pin connector	0402-50001-001	Wire bus, 2 wires, Grey, 28AWG, 40 cms			1	EA	4.92	4.92	0.1	0.1	4.915	4.75	4.5
2-pin connector	0025-00002-002	Connector, housing, 2.5mm pitch, 2 pins	Molex	50375023	1	EA	1	1	0.02	0.02	1	0.9	0.8
Water Layer	0712-50002-000	SA, 4-pin connector housing, with 28AWG bus wire, grey			1	Ea	9.83	9.83	0.2	0.2	9.829	8.9	8
Water Layer	0128-50001-000	Aluminum laminate film - Water layer	Floeter		1	Ea	25	25	0.5	0.5	25	23	21
Water Layer	0917-00002-000	Water, filtered, drinking water	Hussain Distributers	N/A	0.75	L	2.43	1.82	0.05	0.04	2.43	2.43	2.43
Water Layer	0047-00003-000	THERMISTORS, NTC, R25=83K +/-3%, , R37=51.	Nanjing Shiheng Electronics	MF51E 833 H 3953	2	Ea	20	40	0.4	0.8	19.98	17.5	15
Water Layer	0509-00001-000	Clear adhesive Tape, 25mm width	OTS	OTS	50	mm	1	50	0.02	1	1	0.9	0.8
Water Layer	0905-00016-000	425 aluminum tape	3M	70006386968	1	625mn	1.41	1.41	0.03	0.03	1.409	1.4	1.4
Water Layer	0920-00015-000	Insulation, 4 oz (polyfill), 100% Polyesteer, 120	Rajeshwari Enterprises		1	625mn	0.5	0.5	0.01	0.01	0.5	0.475	0.45
Water Layer	0307-50033-000	Sticker - Water layer	Printo		1	Ea	95	95	1.9	1.9	95	87.5	70
Water Layer	n/a	Sticker to cover heat sealing marks	Printo		1	Ea	5.94	5.94	0.12	0.12	5.938	5.25	4.5
PCM Layer	0128-50002-000	Aluminum laminate film - PCM layer	Floeter		1	EA	25	25	0.5	0.5	25	23	21
PCM Layer	0918-00001-000	PCM	Entropy Solutions Inc	Pure Temp 37	0.5	kg	399	200	7.98	3.99	399	375	350
4-pin connector	0712-50002-000	4-pin connector assembly	Molex	5375043, 8701039	1	EA	12.8	12.8	0.26	0.26	12.83	12	11
Assembly	0905-00016-000	Al Tape	3M	70006386968	0.08	m	56.4	4.23	1.13	0.08	56.36	53.18	50
Assembly	0123-00004-000	Staples, No. 23/10-H (10mm)	Kangaro	23/10-H (10mm)	12	EA	0.01	0.16	0	0	0.013	0.012	0.011
Assembly	0307-50034-000	Sticker - Tab	Printo		1	EA	1.19	1.19	0.02	0.02	1.188	0.95	0.8
Electronics Box	0212-5002*-000	Diffusers	Mount Diffuser		0	M	1614	1.61	32.3	0.03	1614	1550	1450
Electronics Box	0704-50003-000	Enclosure Box	Guru Enterprises	Pad Printing	1	EA	65	65	1.3	1.3	65	57.5	50
Electronics Box	0212-50024-000	Enclosure Box (Printed)	Huli Xiamen		1	EA	113	113	2.27	2.27	113.4	85	70
PCB	0701-50003-001	PCB	Southern Chips		1	EA	700	700	14	14	700	625	550
PCB	0047-00003-000	Thermistor	Nanjing Shiheng Electronics	MF51E 833 H 3953	2	EA	20	40	0.4	0.8	19.98	17.5	15
PCB	0402-00016-000	Teflon Wire AWG 22/7/30	K & M cables		0.16	m	11.9	1.9	0.24	0.04	11.9	10.5	9
PCB	0110-00002-000	Battery Terminal	Keystone	5201, 5223	1	EA	15.5	15.5	0.31	0.31	15.53	13.75	12
Assembly	0102-50001-000	Screws: Slotted M4x8mm	Huli Xiamen		5	EA	10	50	0.2	1	10	9.25	8.5
Assembly	0201-50003-000	Top Tray	Dhanya		1	EA	36	36	0.72	0.72	36	34	32
Assembly	0201-50004-000	Bottom Tray	Dhanya		1	EA	185	185	3.7	3.7	185	180	175
Assembly	0207-50010-000	Silicone Border	Brahad Elastomers.		1	EA	25	25	0.5	0.5	25	24	23
Assembly	0905-00002-000	RTV Adhesive	Momentive Performance Materials	IS 9188	12	mL	0.92	11	0.02	0.22	0.917	0.885	0.85

APPENDIX K: Cost Analysis Results
(from ME 317)

Original SmartPak			
90%	Low	High	
100 units/mo	1325	1765	(INR)
	26.5	35.3	(USD)
1000 units/mo	1000	1300	(INR)
	20	26	(USD)

2Pouch SmartPak			
90%	Low	High	
100 units/mo	1325	1765	(INR)
	26.5	35.3	(USD)
1000 units/mo	1000	1300	(INR)
	20	25.9	(USD)

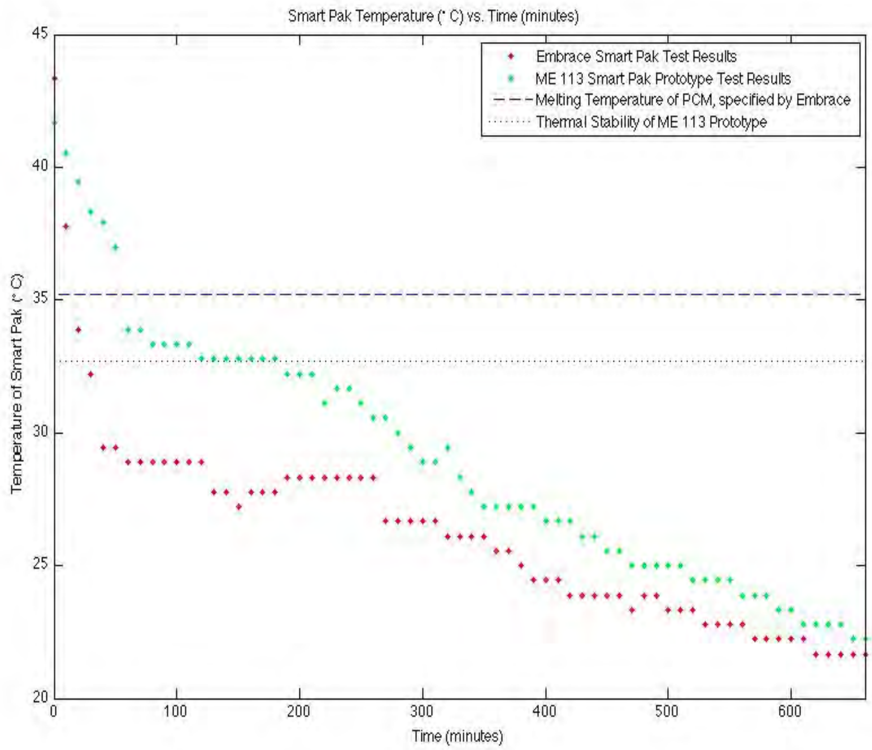
Table 3: Monte Carlo Assembly and Labor 90% CI's for Original SmartPak

Original SmartPak				
	90%	Low	High	
		257	287	(min)
		4.28	4.78	(hr.)
Labor Rate				
1.765	(USD/hr.)	7.56	8.44	(USD/unit)
88.25	(INR/hr.)	378.00	422.13	(INR/unit)

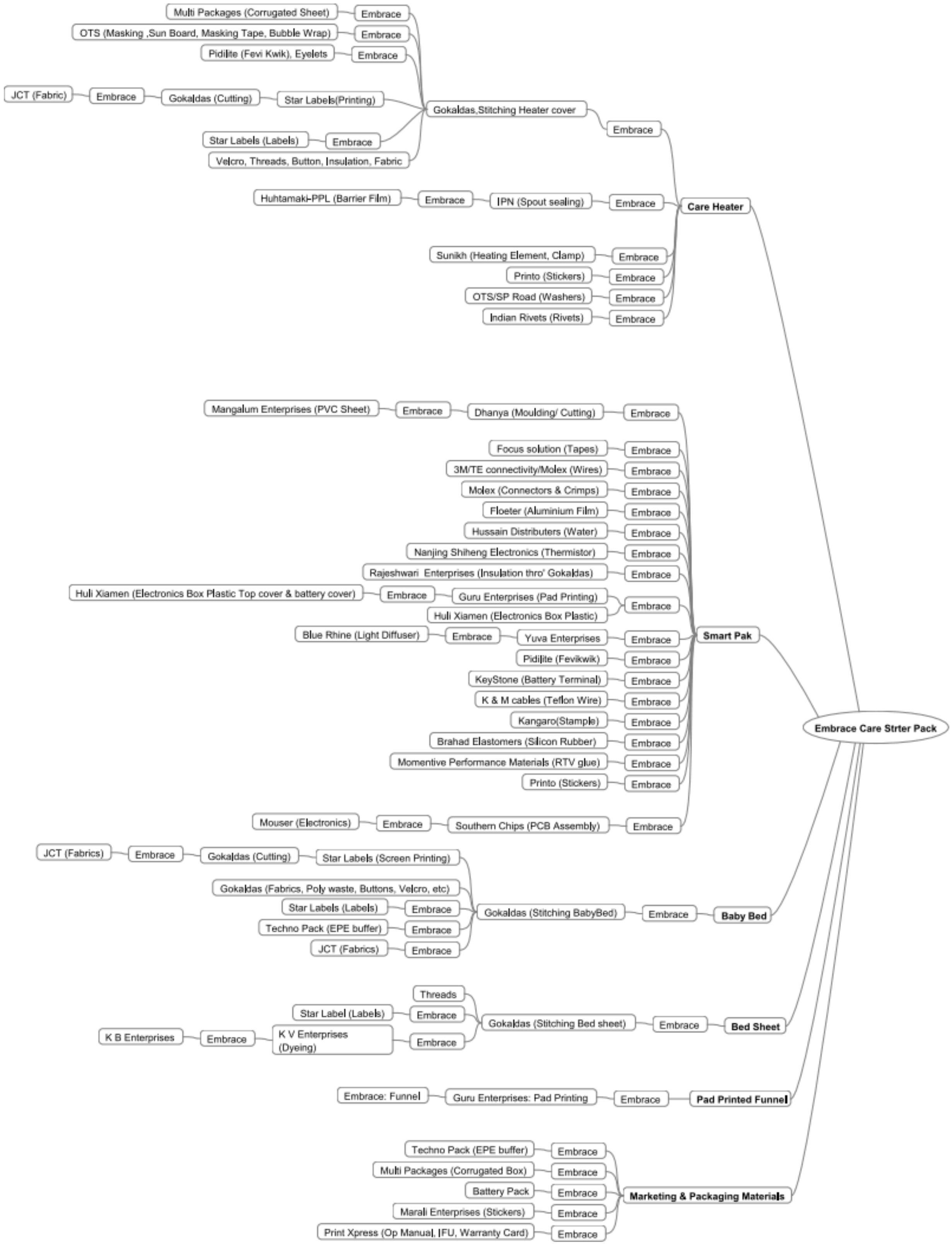
Table 4: Monte Carlo Assembly and Labor 90% CI's for 2Pouch SmartPak

2Pouch SmartPak				
	90%	Low	High	
		225	265	(min)
		3.75	4.42	(hr.)
Labor Rate				
1.765	(USD/hr.)	6.62	7.80	(USD/unit)
88.25	(INR/hr.)	330.94	389.77	(INR/unit)

APPENDIX L: Testing Results



APPENDIX M: Sourcing Map



APPENDIX M: Matlab Code and Testing Results

```
clear all
close all

Time=0:10:660; %units:minutes

PCMmeltingtemp=35.2; %Melting temperature of PCM, specified by Embrace, units in degrees Celsius
StableTemp=35.7;  %temperature at which the ME 113 prototype started to stabilize, units in degrees celsius

plot(Time,EmbracePrototypeTemperature,'r.', Time,ME113PrototypeTemperature, 'g.', 'LineWidth', 4)
line([0 Time(end)], [PCMmeltingtemp PCMmeltingtemp], 'LineStyle', '--')
line([0 Time(end)], [StableTemp StableTemp], 'LineStyle', ':')

title('Smart Pak Temperature ({\circ}C) vs. Time (minutes)')
ylabel('Temperature of Smart Pak ({\circ}C)')
xlabel('Time (minutes)')
xlim([0 660])

legend ('Embrace Smart Pak Test Results', 'ME 113 Smart Pak Prototype Test Results', 'Melting Temperature
of PCM, specified by Embrace', 'Thermal Stability of ME 113 Prototype')
```